CHAPTER 7
THE X-RAY TUBE

X-ray Tube
- A special type of diode (anode & cathode)
- It converts electrical energy to electromagnetic energy

Diode
- Any tube with two electrodes

EXTERNAL COMPONENTS

External Structures
- Support Structure, Protective Housing & Glass/Metal Enclosure

Ceiling-Support System
- It consists of two perpendicular sets of ceiling-mounted rails
- Most frequently used
- It allows both longitudinal & transverse travel of the x-ray tube

Preferred Detent Position
- When x-ray tube is centered above the examination table at the standard SID

Floor-To-Ceiling Support System
- It consists a single column with rollers at each end
- The x-ray tube slides up & down the column as the column rotates
- *Variation:* single floor support system

C-Arm Support System
- C-shaped & ceiling mounted system
- It provides for very flexible x-ray tube positioning
- *Variations:* L-arm or U-arm

Protective Housing
- Lead-lined metal container into which the x-ray tube is fitted
- *3 Functions:*
  - Insulator (*diala oil*) against electric shock
  - Thermal cushion to dissipate heat
  - Mechanical support for the tube & protect it from damage caused by rough handling
- *Properly Designed:* reduces level of leakage radiation to less than 100 mR/hr at 1m

Isotropic Emission
- Emission with equal intensity in all directions

Window
- A thin section of a glass/metal envelope through which useful beam emerges
- *Size:* 5 cm^2

Useful Beam/Primary Radiation
- X-rays emitted through the window

Leakage Radiation
- X-rays that escape through protective housing

Glass/Metal Enclosure
- It contains the x-ray tube & its components

Glass Enclosure
- Pyrex glass
  - Able to withstand tremendous heat generated
- *Disadvantages:*
  - More likely to fail
  - Lesser tube life

Metal Enclosure
- Maintain constant electric potential between the electrons of the tube current & the enclosure
- *Advantages:*
  - Less likely to fail
  - Longer tube life

X-ray tubes are designed with a glass or metal enclosure!

CHAPTER 7
THE X-RAY TUBE

INTERNAL COMPONENTS

Cathode
- The negative side of the x-ray tube
- *2 Primary Parts:* filament & focusing cup

Filament
- A coil of wire that emits electrons when it is heated
- Made of thoriated tungsten
  - Additional 1-2% thorium:
    - Enhances the efficiency of thermionic emission
    - Prolongs tube life
- *Tungsten:* Z=74; melting point=3410^{o} C
  - Provides higher thermionic emission
  - Does not vaporize easily
  - If vaporized, can cause arcing & can lead to tube failure

Tungsten vaporization with deposition on the inside of the glass enclosure is the most common cause of tube failure!

Focusing Cup
- Metal shroud that surrounds the filament
- Its effectiveness is determined by:
  - Its size & shape
  - Its charge
  - Filament size & shape
  - Position of the filament
- It serves as a *grid* (exposure switch) in grid-controlled x-ray tube

The x-ray tube current is adjusted by controlling the filament current!

Space Charge
- Cloud of electrons

Space Charge Effect
- A phenomenon of the space charge that makes it difficult for subsequent electrons to be emitted by filament because of electrostatic repulsion

Thermionic emission at low kVp & high mA can be space charge limited!

Saturation Current
- Filament current that has risen to its maximum value because all available electrons have been used
- *X-ray tube at Saturation Current:* emission limited

Focal Spot
- A region of the anode target in which electrons interact to produce x-rays
- The actual x-ray source
- *Sizes:* small (0.1-1 mm)/large (0.3-2 mm)
- *Shapes:* circular (preferred)/double banana

Round Focal Spot
- Important for high resolution magnification radiography & mammography

Small Focal Spot
- It is used when small body parts are image & when better spatial resolution is required
- It is associated with the small filament
- *Limiting Factor:* the heating of the target is concentrated onto smaller area

Large Focal Spot
- It is used when large body parts are imaged
- It is associated with the large filament

Anode
- The positive side of the x-ray tube
- It conducts electricity, radiates heat & contains the target
- *2 Types*: stationary/rotating
- *3 Functions:*
  - Electrical conductor
  - Mechanical support for the target
  - Thermal dissipator
- *3 Most Common Anode Materials:*
  - Copper (Cu-29), Molybdenum (Mo-42) & Graphite

- *Mo & Graphite:*
  - Lower mass density than tungsten
  - Make anode lighter & easier to rotate

Stationary Anode
- It is used when high tube current & power are not required
  - Dental x-ray imaging system
  - Portable x-ray imaging system

Target
- The area of the anode struck by the electrons from the cathode
- *Stationary:* tungsten alloy embedded in the copper anode
- *Rotating:* entire rotating disk
- Alloying the tungsten with rhenium
  - Added mechanical strength to withstand stresses (high-speed rotation) &
  - The effects of high repetitive expansion & contraction
- *Mammographic Targets:* Mo (Z=42) & Rh (Z=45)

Tungsten (Z=74)
- The material of choice for the target
- *3 Main Reasons:*
  - *Atomic Number (Z):* high Z results in high efficiency x-ray production & high energy x-rays
  - *Thermal Conductivity:* efficient material for dissipating heat
  - *High Melting Point:* can stand up under high tube current w/o pitting or bubbling (W=3410^{o} C compared with Cu=3000 ^{o}C)

Rotating Anode
- It allows the electron beam to interact with a much larger target area
- 3,600-10,000 rpm

Higher tube currents and shorter exposure times are possible with the rotating anode!

Anode Stem
- The shaft between the anode & the rotor
- *Composition:* Molybdenum
  - *Characteristic:* poor heat conductor

Electromagnetic Induction Motor
- It is used to turn the anode
- *2 Principal Parts:* stator & rotor

Stator
- Located outside the enclosure
- Stationary coil windings (electromagnets)

Rotor
- Located inside the glass envelope
- Rotating part (shaft)

Coast Time
- Time it takes the rotor to rest after use
- Approximately 60 s

Line Focus Principle
- Design incorporated into x-ray tube targets
- Allows large area for heating while maintaining a small focal spot
- *Result:* effective focal spot much smaller than the actual focal spot
- As the target angle decreases, the effective focal spot size also decreases
- *Limiting Factor:* the ability of the cone of x-rays produced to adequately cover the largest field size used

Effective Focal Spot/Effective Target Area
- The area projected onto the patient & image receptor

Actual Focal Spot
- The area on the anode target that is exposed to electrons from the tube current

Anode Heel Effect
- Consequence of line focus principle
- Absorption of x-rays in the heel of the target
- *Results:*
  - Smaller effective focal spot

    - Radiation intensity on the cathode side (120%) of the x-ray field is greater than that on the anode side (75%)
- The smaller the anode angle, the larger is the heel effect
- *Important Consequences:*
    - Thicker part (cathode side); Thinner part (anode side)
    - Larger effective focal spot size (cathode), Smaller effective focal spot size (anode side)

Central Ray
- The imaginary line generated by the centermost x-ray in the beam

Off-Focus Radiation/Extrafocal X-rays
- X-rays produced in the anode but not at the focal spot
- *Results:*
    - Increases skin dose
    - Reduces image contrast
    - Exposure of tissue that was intended to be excluded by collimator
- *Geometric solutions:*
    - Designing a fixed diaphragm in the tube housing near the window of the x-ray tube
    - Metal enclosure x-ray tube

X-RAY TUBE FAILURE

Factors Affecting X-ray Tube Life
- *Increased:*
    - Minimum radiographic factors – mA, kVp & exposure time
    - Faster image receptors
- *Decreased:*
    - Excessive heat

Three Ways of Heat Dissipation
- Radiation, Conduction & Convection

Radiation
- The transfer of heat by the emission of infrared radiation

Convection
- The transfer of energy from one area of an object to another

Convection
- The transfer of heat by the movement of a heated substance from one place to another

Causes of Tube Failure
- A single excessive exposure
    - *Causes:* pitting & cracking
- Long exposure time causes excessive heating of the anode
    - *Results:* damage to the bearings on the rotor assembly
        - *Causes:* warping & rotational friction of the anode
- Vaporization of the filament:
    - Causes tungsten to coat the glass/metal enclosure
        - *Causes*: arcing

The most frequent cause of abrupt tube failure is electron arcing from filament to enclosure due to vaporized tungsten!

RATING CHARTS

X-ray Tube Rating Chart
- It guides & aids the radiographer in using x-ray tubes & acceptable exposure levels to maximize x-ray tube life

Three Types of Rating Charts
- Radiographic Rating Chart
- Anode Cooling Chart
- Housing Cooling Chart

Radiographic Rating Charts
- Most important
- It conveys which radiographic techniques are safe & unsafe for x-ray tube operation

Anode Cooling Chart
- It is used to determine the thermal capacity of an anode & its heat dissipation characteristics

- It is also used to determine the length of time required for complete cooling after any level of heat input

Heat/Thermal Energy
- *SI Unit:* calories
- *British Unit:* joules
- *X-ray Applications:* heat units (HU)
- 1 HU = 1 kVp x 1 mA x 1 s
- 1 HU = 1.4 J (3Ø, HF)
- 1 J = 0.7 HU (3Ø, HF)

Single-Phase
- HU = kVp x mA x s

Three-Phase 6 pulse
- HU = 1.35 x kVp x mA x s

Three-Phase 12 pulse
- HU = 1.41 x kVp x mA x s

High Frequency
- HU = 1.45 x kVp x mA x s

Housing Cooling Chart
- It is used precisely in the same way as anode cooling chart
- *Complete cooling:* 1-2 hrs